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(54) IMPROVEMENTS IN AND RELATING TO VARIABLE REACTORS AND TRANSFORMERS

(71) I DONALD LIONEL HORE, a British Subject, of 10, Charnhill Vale, Mangotsfield, Bristol BS17 3JT, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to variable reactors and transformers.

The reactors and transformers of the present invention have constructional features in common with a squirrel cage induction motor in that a rotor is provided with a plurality of short circuited low voltage windings having no external connections.

One object of the invention is to provide a variable reactor wherein the relative positions of the stator and rotor determine the reactance of the reactor.

Another object of the invention is to provide a variable autotransformer, wherein the relative positions of the stator and rotor determine the magnitude of the output voltage of the transformer.

A further object of the invention is to provide a variable buck/boost regulator wherein the relative positions of the stator and rotor determine the relationship of the output voltage across the secondary windings of the regulator to the supply voltage to vary the voltage across a load supplied from a primary supply voltage.

Another object of the invention is to provide a single-phase double-wound variable transformer or buck/boost regulator wherein the relative positions of the rotor and stator determine the relationship of the voltages across the primary, secondary and rotor short circuited windings and thus, the relationship of the output voltage to the supply voltage.

A further object of the invention is to provide a three-phase, phase-shifting regulator wherein separate primary and secondary windings per phase, are arranged on the stator such that rotation of the rotor progressively links the secondary winding with each primary phase winding in turn.

According to the present invention there is provided a single or multi-phase variable reactor or variable auto or double wound transformer including a stator having at least one winding wound thereon, and a cylindrical rotor separated from the stator by a constant air gap and having a plurality of only short circuited windings so disposed thereon as to provide for the single or each multiple phase, a path of variable reluctance to the passage of alternating magnetic flux to thereby influence the reactance of the stator windings according to the position of the rotor relative to the stator, the short circuited windings on the rotor constraining the flux to follow paths parallel to the plane of the short circuited windings and mechanical means for effecting rotation of the rotor.

Several embodiments of the invention will now be described by way of example only with particular reference to the accompanying drawings wherein:

Figure 1 is a perspective view of the single phase rotor of a variable reactor showing the typical disposition of the short circuited windings and mechanical operating mechanism;

Figure 2 is a diagrammatic view of a three phase rotor 'cage' of a variable reactor showing a typical disposition of the short circuited windings;

Figures 3*a* and 3*b* are diagrammatic views of the rotor and stator of a single-phase variable reactor with the rotor shown in the maximum and minimum reactance positions respectively;

Figures 3*c* and 3*d* are diagrammatic views of the rotor and stator of a three-phase

variable reactor with the rotor shown in the maximum and minimum reactance positions respectively;

Figures 4*a* and 4*c* are diagrammatic views of a single-phase and a multi-phase variable autotransformer respectively;

Figures 4*b* and 4*d* are the equivalent circuit diagrams of the single-phase and three-phase autotransformers of Figures 4*a* and 4*c* respectively.

Figure 5*a* is a diagrammatic view of a single-phase variable transformer similar to that of Figure 4*a* but with additional primary and secondary windings;

Figure 5*b* is a view similar to that of Figure 5*a* but with the rotor moved through 45° to provide a buck/boost regulator;

Figure 5*c* is an equivalent circuit diagram of the arrangement of Figure 5*a* connected as a single-phase variable auto-transformer;

Figure 5*d* is an equivalent circuit diagram of the arrangement of Figure 5*b* connected as a buck/boost regulator;

Figure 5*e* is a diagrammatic view of a three-phase version of the autotransformer of Figure 5*a*;

Figure 5*f* is an equivalent circuit diagram of the arrangement of Figure 5*e*;

Figure 6*a* is a diagrammatic view of a single-phase variable transformer with the rotor and stator arranged for maximum flux linkage of the primary and secondary windings;

Figure 6*b* is a view similar to that of Figure 6*a* but with the rotor arranged for zero flux linkage;

Figure 6*c* is a view similar to that of Figure 6*a* but with the rotor arranged for maximum reversed flux linkage;

Figure 6*d* is an equivalent circuit diagram of the arrangement of Figure 6*c* for buck/boost regulation;

Figure 7*a* is the three-phase equivalent of the single-phase variable transformer of Figure 6*a* and

Figure 7*b* shows the rotor of the transformer of Figure 7*a* turned through 30° to vary the flux linkages between the primary and secondary windings.

Referring to Figure 1, the rotor winding arrangement for the single-phase two pole construction consists of three sets of coils A, B, C, arranged in longitudinal slots in parallel planes in a laminated iron core D. It will be seen that with the rotor in the position shown, alternating magnetic flux can pass freely in a horizontal direction across the iron rotor D but any vertical component of flux must link one or more of the short circuited coils A, B, C, to induce therein a current in a direction opposed to the passage of the flux.

A manually operable worm E arranged to mesh with a quadrant gear F on the rotor shaft G, enables the position of the rotor to be varied and the rotor to be secured against electro-magnetic reaction forces. The stator housing and bearings of the rotor have not been shown.

Figure 2 shows the typical disposition of the short circuited windings of the "cage" of a 3-phase rotor. Each line H represents a set of conductors laid in a respective slot in the rotor laminations, and joined to form a series of longitudinal loops per phase lying in parallel planes. One end of the rotor may have the conductors H joined into a common end ring as shown at J, but the conductors are generally connected as indicated at K. Such a construction thus forms three pole faces X, Y, X. Only alternating flux entering the rotor through one of these faces and leaving through another is linked with the short circuited windings, whilst flux can enter and leave the same pole face without such linking.

Multipole constructions using the same principles as those described for the arrangements of Figure 1 and 2 may be provided. In the above and all subsequent embodiments of the invention, the number of conducting loops is exemplary only and the nature and distribution of the windings can be varied in accordance with design requirements.

A single phase variable reactor is shown in Figures 3*a* and 3*b* and includes a single stator winding A shown with the coil axes horizontal and the rotor shown arranged such that the short circuited coils X have a vertical axis indicated by arrow *x*. With the rotor positioned as shown in Figure 3*a*, the flux produced by an alternating voltage applied to the stator winding A is free to pass across the rotor i.e: the stator flux does not link the rotor coils, and thus the stator winding has maximum reactance.

By moving the rotor through 90° to the position shown in Figure 3*b* the two coil axes become coincident such that the stator winding A is closely linked to the rotor short circuited coils X, and thus the arrangement behaves as a short-circuited transformer and the stator winding has minimum reactance. Only that flux that does not link both windings i.e: the leakage flux, will give rise to leakage reactance, which can be minimised by electrical machine design techniques. At any position intermediate the positions shown in Figures 3*a*, 3*b*, the reactance will be between the two extremes and the construction illustrated thus operates as a single-phase variable reactor.

A corresponding three-phase version of the reactor is shown in Figures 3*c* and 3*d*, in which phase windings A, B and C scan 120° arcs of the stator. In Figure 3*c*, the rotor is positioned such that the flux produced by phase A for instance, can enter

and leave the rotor along the planes of rotor coil groups X and Z, returning via phases B and C on the stator without linking a rotor short circuited winding, and similarly with a flux produced with the other phases B and C. The stator windings thus have maximum reactance. With the rotor rotated through 60° to the position shown in Figure 3*d*, the stator and rotor coil axes are coincident, such that the stator phase windings are closely linked to the rotor short-circuited windings and have minimum reactance. The construction of Figures 3*c*, 3*d* thus operates as a three-phase variable reactor.

A single phase arrangement generally similar to that of Figure 3*a* is shown in Figure 4*a*, but with an additional stator winding B having the axis spaced 90 electrical degrees from the axis of stator coil A. It is apparent that the reactance of stator winding B will be a minimum when that of winding A is a maximum, and vice versa. If windings A and B are connected in series across an a.c. supply, the voltage across one winding will vary from minimum to maximum as the reactance thereof changes correspondingly. The voltage across a load connected across the winding will thus vary in accordance with the relative positions of the stator and rotor. An equivalent circuit diagram is shown in Figure 4*b*.

Similarly, a three-phase variable autotransformer can be produced with the stator/rotor construction shown in Figure 4*c*. This is similar to the construction shown in Figure 3*c* with the addition of stator windings A2, B2, C2 spaced at 60 electrical degrees from stator windings A1, B1, C1. These windings are connected as shown in Figure 4*d* to produce a three-phase variable voltage output.

From the previous embodiments it is apparent that secondary windings can be laid in the stator slots in proximity to the primary windings. Figure 5*a* shows a single construction similar to that of Figure 4*a* but modified by the addition of secondary windings S1, S2, in association with primary windings P1, P2 respectively. The voltage induced in winding S1 will be a maximum when the reactance of primary winding P1 is maximum and similarly with secondary winding S2 on rotation to the respective primary winding P2.

The voltages in secondary winding S1, S2 may be added to a voltage across a primary winding in the autotransformer construction as shown in Figure 5*c* to extend or modify the voltage range of the simply auto transformer.

In an alternative embodiment of the invention, the secondary winding may be used independently or in conjunction in series with a load fed from the same primary supply or from a separate supply of the same phase and frequency, to increase or decrease the voltage across the load. Such an arrangement is shown in Figure 5*d* wherein the load is fed from the primary supply through the two secondary windings S1, S2, and these are connected relative to the primary windings P1, P2, such that at one extreme rotor position the secondary output adds to the voltage, and at the other extreme position is subtracted from the voltage. The machine thus functions as a buck/boost regulator which is advantageous when the range of the voltage variation is not great, because the secondary windings can be of greater current carrying capacity, and the rating of the machine only needs to be the difference between maximum and minimum load kVA instead of being equal to maximum kVA in the case of the autotransformer embodiments.

In such buck/boost regulators, it is important that the secondary winding reactance should be minimum when the rotor is in the mid-position because the impedance of the secondary windings in series with the load will cause a voltage drop and consequently will cause voltage regulation with change of load.

Because the relationships of the primary and secondary windings and the rotor position are variable to suit design requirements, the performance characteristics are readily variable. From the arrangement of Figure 5*b*, it can be seen that if windings S1 and S2 are arranged such that the fluxes produced by load current are in the relative direction shown, the direction of resultant flux will be such that the secondary winding reactance will be minimum with the rotor at the mid-position.

Figures 5*e* and 5*f* show the equivalent three-phase construction which may be used to provide a three-phase autotransformer of increased or modified voltage range, or a three-phase buck/boost regulator.

It should be particularly noted that variable reactors or transformers constructed in accordance with the invention enable any range of voltage regulation to be achieved, and that regulation is achieved without phase-shift. Additionally, the facility of obtaining single-phase or 3-phase stepless buck/boost regulation from a single machine is a considerable advantage over variable transformers of the sliding contact type which require a separate isolating transformer to achieve economical buck and boost regulation.

All the constructions of the embodiments so far described have utilized the ability of the reactor or transformer to vary the relative reactances of stator windings. The rotor short circuited windings can also be

utilized to considerable advantage, to vary the flux distribution between the stator windings.

Referring to Figure 6*a*, there is diagrammatically shown a single phase machine having primary windings P1, P2 spanning arcs of 90 electrical degrees on diametrically opposite sides of a stator and secondary windings S1, S2, similarly disposed in the remaining arcs. If primary windings P1, P2 are connected such that they produce fluxes in the directions indicated by the arrows on the dotted lines of Figure 6*a*, and the rotor is in the position shown, then these alternating fluxes are free to pass across the rotor to link secondary winding S1 with primary winding P1 and secondary winding S2 with primary winding P2. Thus, the voltage induced in the secondary windings will be a maximum. If the rotor is now rotated through 45° to the position shown in Figure 6*b*, the flux is allowed to pass directly across primary windings P1, P2 without linking secondary windings S1 or S2 such that the voltage induced in windings S1, S2 will be substantially zero and thus the machine operates as a single-phase variable double wound transformer.

If the rotor is rotated through a further 45° to the position shown in Figure 6*c* secondary windings S2 and S1 are linked with primary windings P1, P2 respectively, and thus the direction of flux linking the secondary windings is reversed from that shown in Figure 6*a*, and the secondary voltage will be a maximum but in phase opposition. It is therefore seen that secondary windings S1, S2 can be connected in series with a load supplied from either the same primary supply (see Figure 6*d*) or a separate supply of equivalent phase and frequency to form a buck/boost regulator. Figure 6*b* shows that when the rotor is displaced 45° from the position shown in Figure 6*a* i.e: displaced to the zero buck and boost position, the secondary windings are closely linked with the rotor short circuited windings and thus have minimum reactance.

The three-phase equivalent of the arrangement of Figures 6*a*, 6*b* is shown in Figure 7*a* wherein the primary and secondary windings of each phase each span arcs of 60 electrical degrees. With the rotor in the position shown in Figure 7*a*, it is seen that secondary windings S1, S2, S3 are linked with primary windings PA, PB, PC, respectively. When the rotor is rotated through 30° to the position shown in Figure 7*b*, winding S1 is linked with primary windings PA, PB, winding S2 with windings PB, PC and winding S3 with windings PC, PA. The voltages induced in the secondary windings will therefore be intermediate in phase with respect to the primary voltages. Rotating the rotor through a further 30° will link windings S1, S2, S3 with windings PB, PC and PA respectively such that the secondary voltages will now have shifted one complete phase from the position shown in Figure 7*a*.

Such an arrangement as described with reference to Figures 7*a*, 7*b* is an equivalent of a conventional three-phase induction regulator but without requiring external connections to the rotor.

WHAT I CLAIM IS:—

1. A single or multi-phase variable reactor or variable auto or double wound transformer including a stator having at least one winding wound thereon, and a cylindrical rotor separated from the stator by a constant air gap and having a plurality of only short circuited windings so disposed thereon as to provide for the single or each multiple phase, a path of variable reluctance to the passage of alternating magnetic flux to thereby influence the reactance of the stator windings according to the position of the rotor relative to the stator, the short circuited windings on the rotor constraining the flux to follow paths parallel to the plane of the short circuited windings and mechanical means for effecting rotation of the rotor.

2. A variable reactor as claimed in claim 1 wherein the stator has a single primary winding for the single or each multiple phase, and the short circuited winding(s) being disposed on the rotor such that at one extreme rotor position, alternating flux passes freely through the rotor to provide maximum reactance whilst at the other extreme position of the rotor the flux is closely linked with the short circuited winding(s) to minimise reactance, with intermediate rotor positions providing reactance intermediate that at the two extreme positions.

3. A variable auto transformer as claimed in claim 1 wherein the stator has two series-connected primary windings for the single or each multiple phase and the rotor short circuited winding(s) being so disposed that at one extreme position of the rotor a primary winding per phase is closely linked with a short circuited winding of the rotor to provide minimum reactance for the primary winding whilst movement of the rotor to the other extreme position thereof progressively varies the reactance in the two primary windings with consequent variation in the voltage across one of the windings per phase with respect to the applied voltage and in accordance with the position of the rotor.

4. A variable auto transformer as claimed in claim 3 wherein the stator is

provided with at least one secondary winding wound in close proximity to either or both of two primary windings per phase, the secondary windings being connected in series with the output winding in additive or subtractive phase relationship with respect to the voltage across a primary winding to effectively increase the output voltage range.

5. A variable auto transformer as claimed in claim 4 and capable of use as a buck/boost regulator wherein the secondary windings are connected in series with a load supplied from the primary supply or from a supply of the same phase and frequency such that the secondary output voltage is in phase with or in phase opposition to the supply voltage, the secondary output voltage varying in magnitude in accordance with the position of the rotor to vary the voltage across the load.

6. A single phase variable double wound transformer as claimed in claim 1 and capable of use as a buck/boost regulator wherein the stator is provided with a separate primary and secondary winding per pole pair on the stator, the short circuited winding(s) on the rotor being disposed such that at one extreme angular position of the rotor, mutual flux linkage between the primary and secondary windings is a maximum, at the central position is a minimum and in the opposite extreme position is a maximum again but reversed in direction in the secondary windings such that the corresponding secondary voltages are respectively maximum in phase, substantially zero and maximum of the opposite phase relative to the primary supply or a separate supply of the same phase and frequency.

7. A variable double wound transformer as claimed in claim 1 wherein the stator is provided with a separate primary and secondary winding per phase per pole pair, the short circuited winding(s) being so disposed that angular movement of the rotor progressively links each secondary winding with each primary winding in turn.

8. A variable transformer as claimed in claims 3, 4, 5 or 6 and capable of use as an angular position transducer wherein an output voltage proportional to the relative position of the stator and rotor is derived from an output winding of the stator.

9. A variable reactor or variable auto or double wound transformer substantially as hereinbefore described and as shown in any one of Figures 1 or 2, 3*a* to 3*d*, 4*a* to 4*d*, 5*a* to 5*f*, 6*a* to 6*d* or 7*a* or 7*b* of the accompanying drawings.

For the Applicant:
F. J. CLEVELAND & COMPANY,
Chartered Patent Agents,
40-43 Chancery Lane,
London, WC2A 1JQ.

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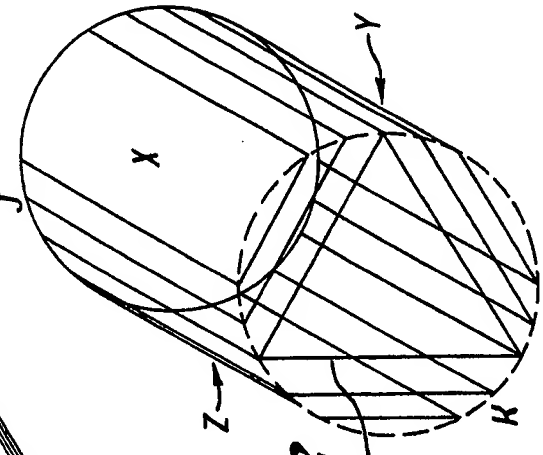


Fig.2

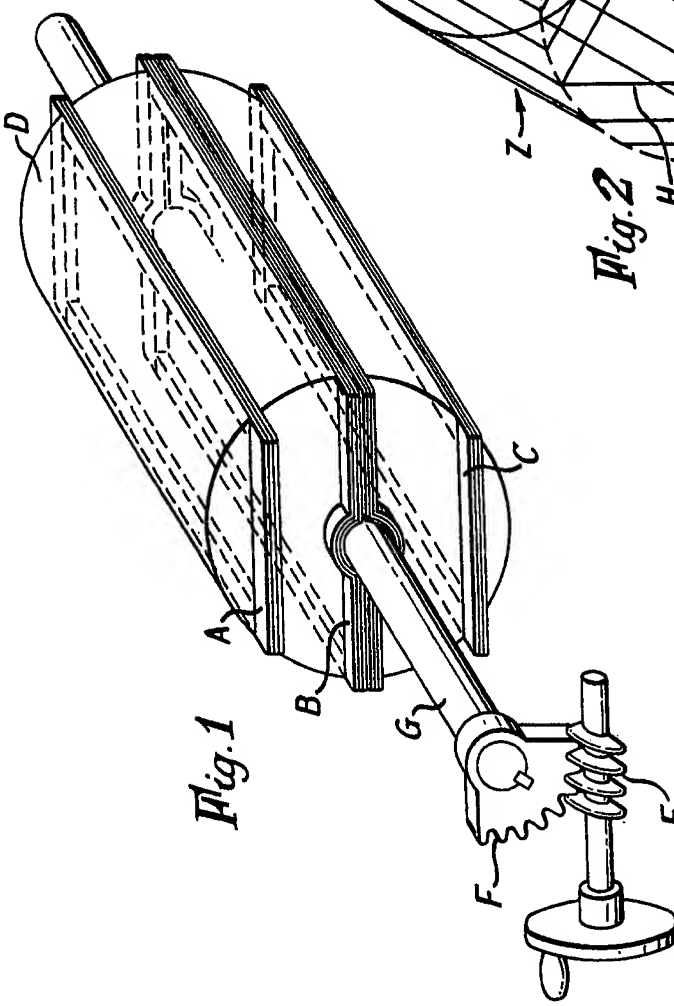


Fig.1

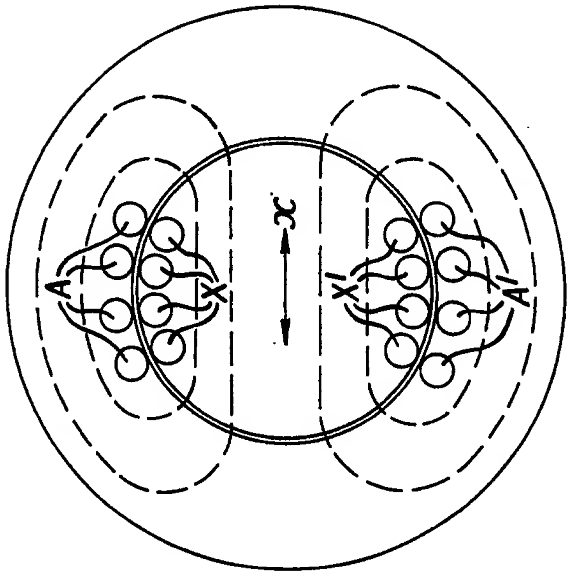


Fig.3b

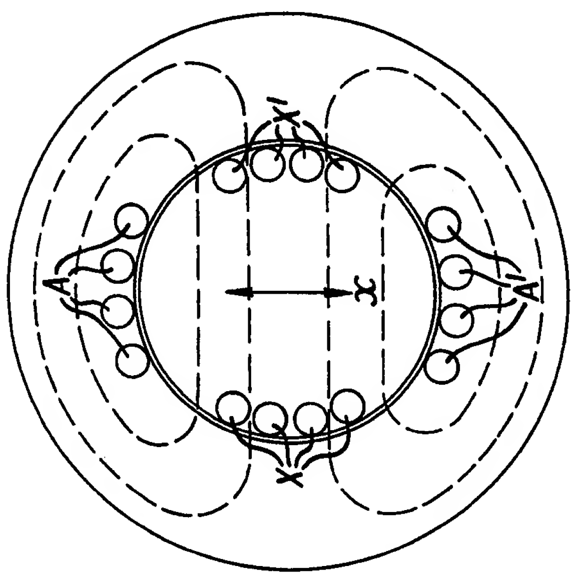


Fig.3a

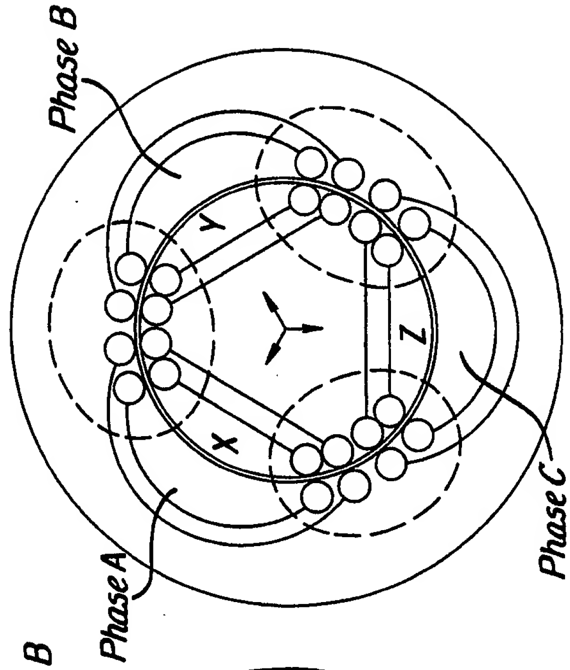


Fig. 3d

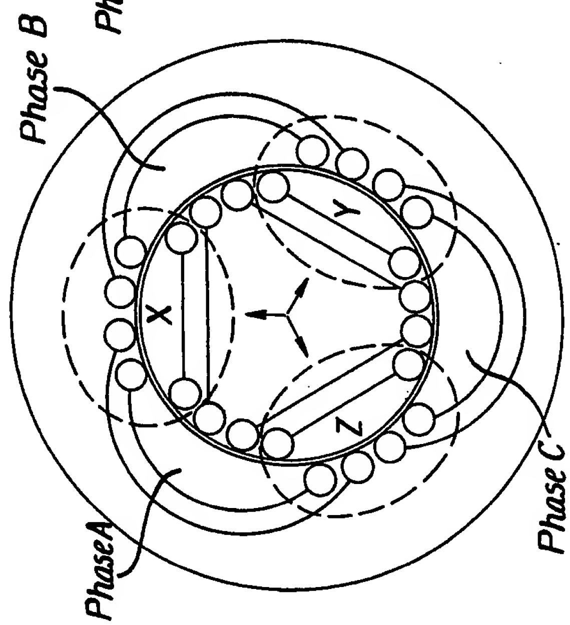


Fig. 3c

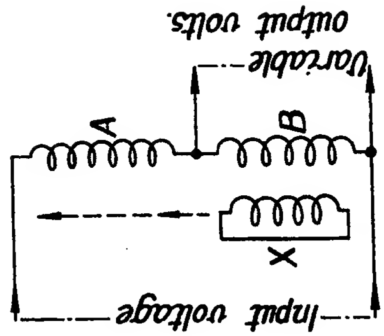


Fig. 4b

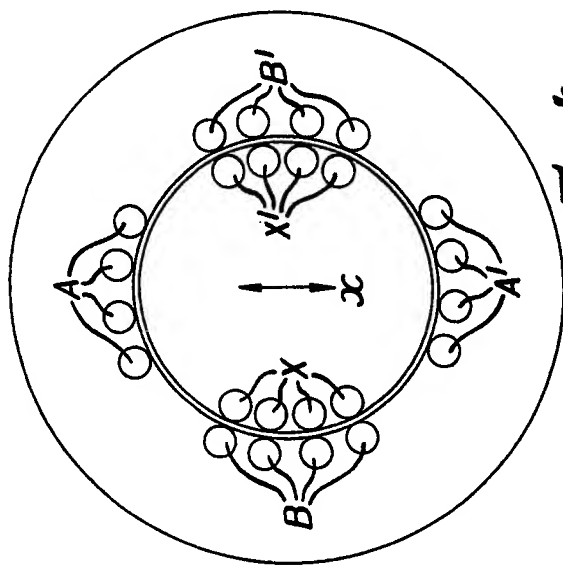


Fig. 4a

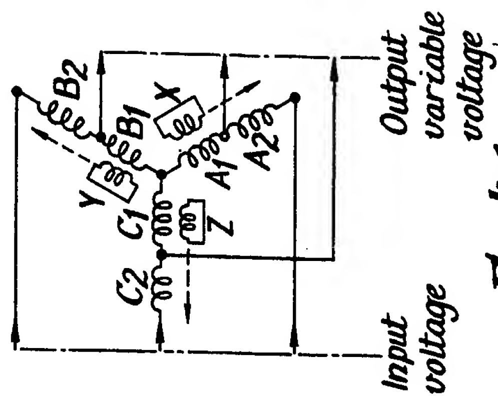

B2
B1
X
Y
C1
A1
A2
Z
C2
Output variable voltage
Input voltage

Fig. 4d

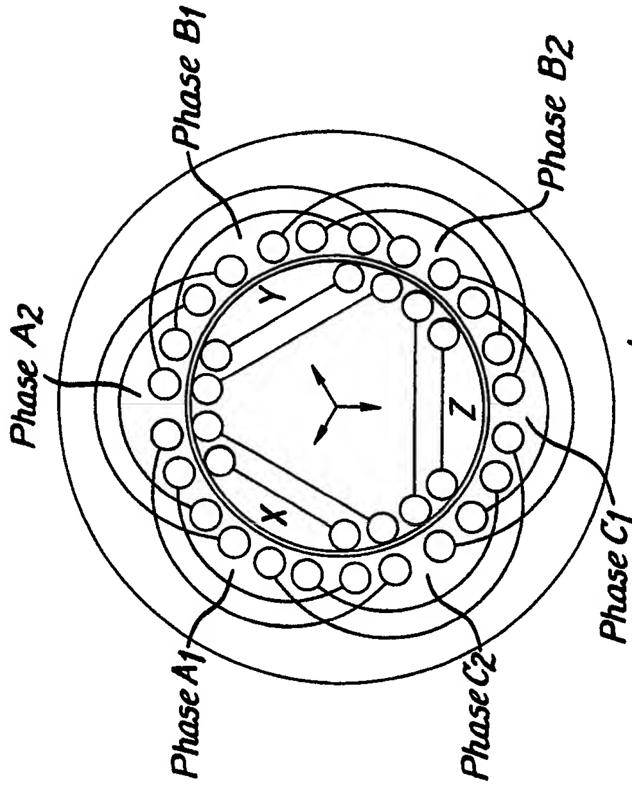

Phase B1
Phase B2
Phase A2
Y
Z
X
Phase C1
Phase A1
Phase C2

Fig. 4c

1433402 COMPLETE SPECIFICATION

11 SHEETS This drawing is a reproduction of the Original on a reduced scale

Sheet 6

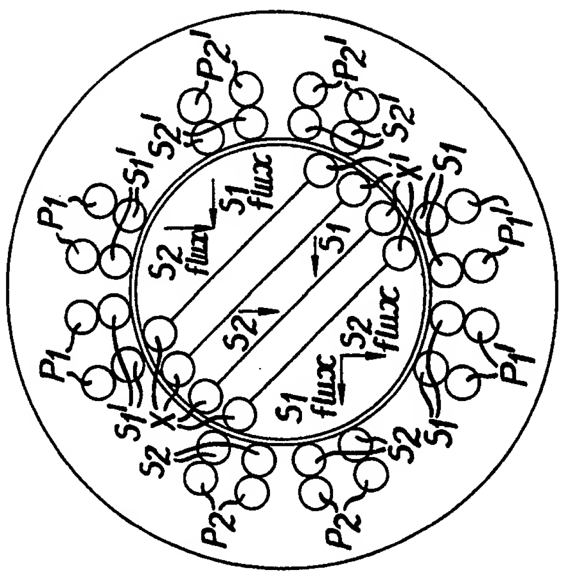


Fig. 5b

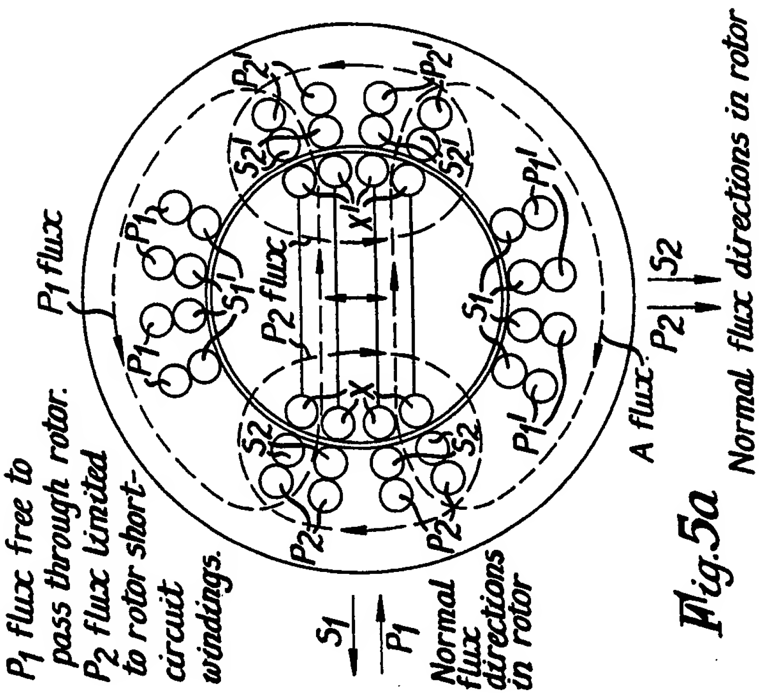
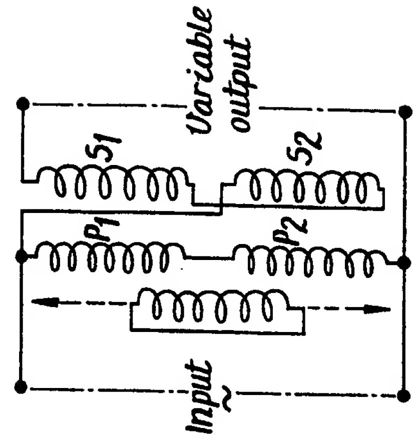
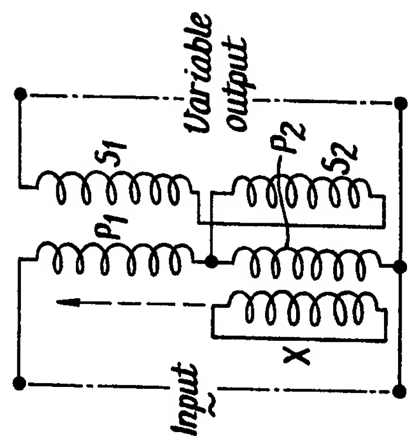


Fig. 5a


Variable output
S1
S2
P1
P2
Input ~
Fig. 5d


Variable output
S1
P2
S2
P1
X
Input ~
Fig. 5c

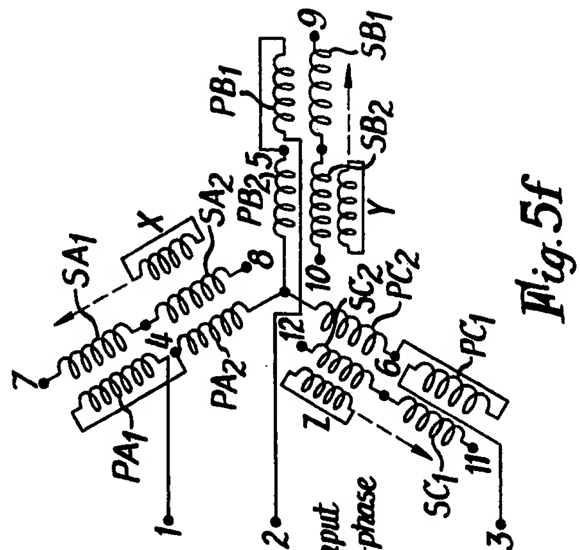

SA1
X
SA2
PB2
5
PB1
9
SB1
SB2
Y
7
4
8
10
SC2
PC2
12
PA1
PA2
6
PC1
Z
SC1
11
1
2
3
Input
3-phase

Fig.5f

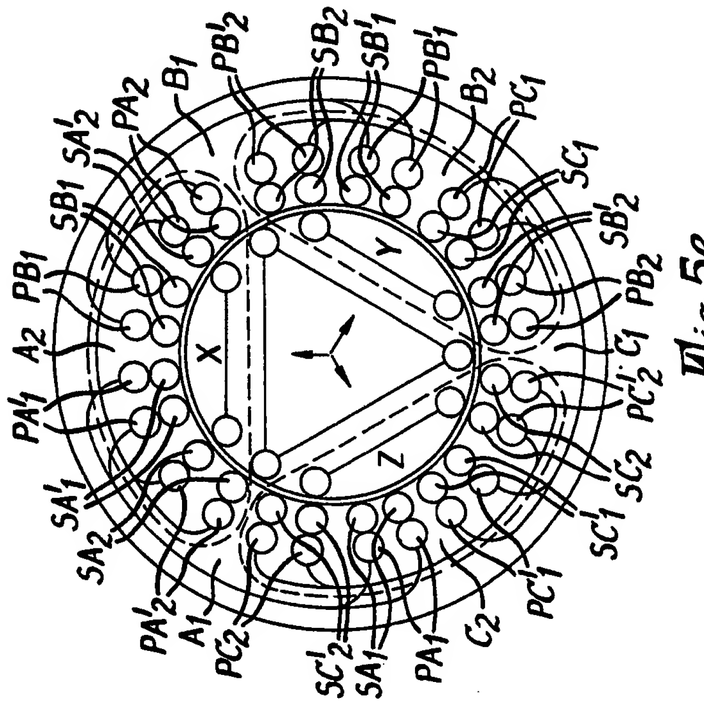

X
Y
Z

Fig.5e

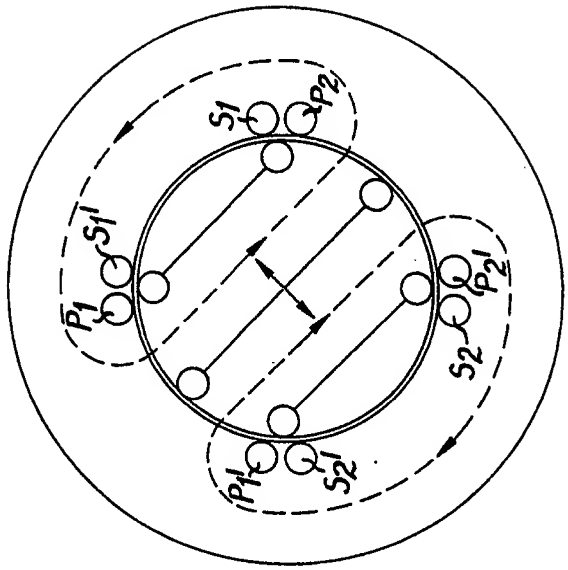


Fig. 6b

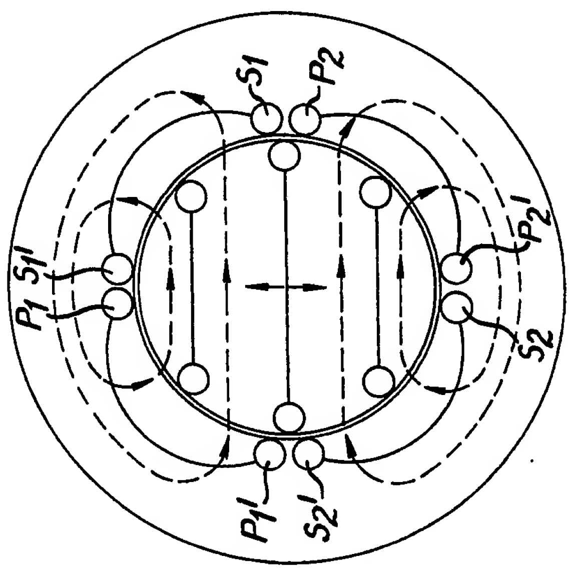


Fig. 6a

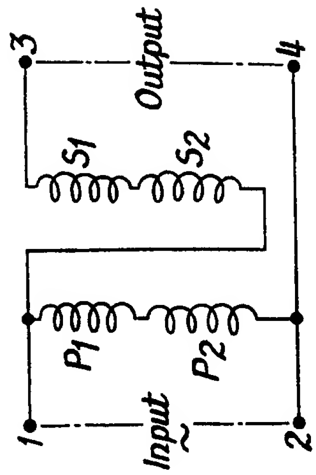


Fig. 6d

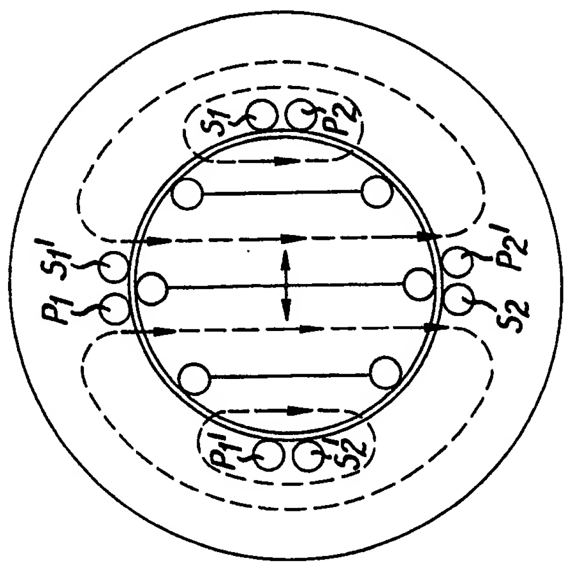


Fig. 6c

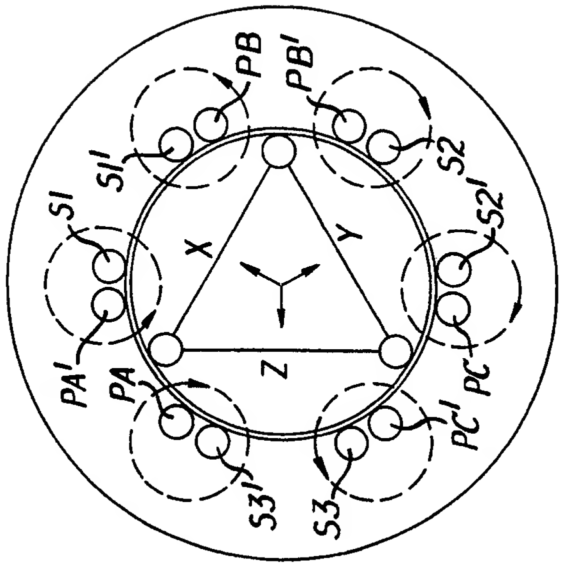

PB
PB'
S1'
S2
S1
S2'
X
Y
Z
PA'
PA
PC
PC'
S3'
S3

Fig. 7b

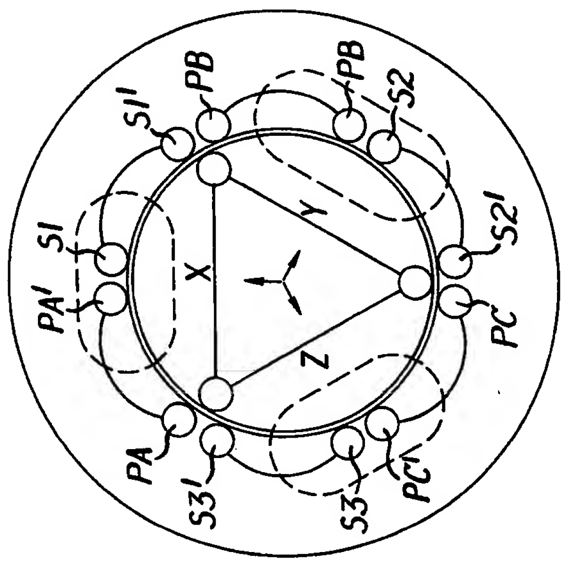

PB
S1'
PB
S2
S1
PA'
X
Y
S2'
Z
PC
PA
S3'
S3
PC'

Fig. 7a